ENGLISH TRANSLATION OF THE INTERNATIONAL APPLICATION

FOR NATIONAL PHASE SUBMISSION

Description

Method for balancing out the differences in the injection quantities between the cylinders in an internal combustion engine

The invention relates to a method for balancing out the differences in the injection quantities between the cylinders in an internal combustion engine in accordance with the preamble of claim 1.

In a multi-cylinder internal combustion engine there is a systematic error in the injection of fuel into the combustion chambers, due to variations, in particular, in the mechanical properties of the injection device, for example of the injectors in diesel engines with a common rail. The manufacturing tolerances for the components mentioned (different idle strokes) mean that, when actuated for the same length of time and with the same actuation energy, different quantities of fuel for combustion are fed to the individual cylinders. The different quantities of fuel lead to different power outputs from the individual cylinders which, apart from raising the running irregularity, also leads to an increase in the quantity of harmful exhaust gas components. In addition, differences in the idle stroke can invoke changes in the opening characteristics of the injectors. This manifests itself by differences in the start of the hydraulic injection between the individual injectors, and in the time-trace of the injection.

The underlying object of the invention is to specify a method of the type mentioned in the introduction which permits the actual systematic errors, which depend on the injection parameters, relevant for balancing out the cylinders to be determined in a simple way in terms of the injection quantities, the start of the hydraulic injection and the time-trace of the injection.

This object is achieved in accordance with the invention by the characteristics of claim 1. The dependent claims relate to advantageous developments and embodiments of the invention.

In accordance with the invention, the method for balancing out the differences in injection quantities between the cylinders of an internal combustion engine carries out an adaptation of the injection quantity differences for at least one selected injection parameter. When doing so, the internal combustion engine will be at a selected operating point. Here, care must be taken to limit the dynamics of the selected operating point during the adaptation, because a changed value of the injection parameter would otherwise manifest itself as a braking or acceleration, not injected by the driver of the vehicle, and in any case as a new operating point, that is unstable conditions during the adaptation.

Next, the differences in injection quantities are determined for the selected operating point, and are learned as adaptation values which are assigned to the injection parameter value concerned. As has already mentioned above, care must be taken that the selected operating point remains essentially static. The second or additional injection parameters, as applicable,

are here controlled as auxiliary variables, in such a way that the driver notices nothing of the adaptation process. Because only a few piston strokes are required for the adaptation, the engine control unit can also simply be adjusted so that the driver cannot terminate the static conditions during the critical adaptation phase, or only if the desired power, as called for by the driver via the throttle, exceeds some threshold.

The adaptation values which have been learned will preferably be used for the calculation of correction factors for individual cylinders, which are applied to an actuation parameter of an injection device on the internal combustion engine during the adaptation process and driving operation, for example as part of the control of running irregularity, in such a way as to effect a balancing out of the injection quantities, the start of the hydraulic injection and the time-trace of the injection.

Here, it has been found to be advantageous that the injection device for each cylinder takes the form of an injector with a piezo-electric actuator, for which the parameters used as the actuation parameters are the duration of actuation, the time point of actuation and/or the duration of the recharging time. It is thus possible, in particular for different values of the injection pressure, to carry out an adaptation of the valve lift required for the purpose of balancing out.

The method in accordance with the invention opens up in addition the possibility that, at the static operating point set for the purpose of adaptation, with balanced up injection

quantities, the absolute value of the associated injection quantity is determined from a stored torque model of the internal combustion engine. A diagnosis of the absolute value of the injection quantity is precisely the critical factor, for the diagnosis of small injection quantities lying in the range of a few milligrams, for adherence to the limiting exhaust gas emission.

It has proved advantageous to set the start and the duration of the recharging of the piezo-electric actuator in such a way that the actuator signal (e.g. needle stop) which is generated should be effected for each injector at the same crankshaft angle, relative to upper working point for the piston concerned in the internal combustion engine.

It is thereby possible, by means of the actuator signal and a displacement of the time-point of actuation, to compensate completely for fluctuations in the injection quantity and also for differences in the start of the injection, due to manufacturing tolerances (e.g. idle stroke). This is particularly evident with pre- and post-injection.

The invention is explained in more detail below by reference to diagrammatic drawings. These show:

Figure 1 a flow diagram for carrying out balancing out of the injection quantities in accordance with the invention

Figure 2 actuation signals and valve lifts for two injectors with different adjustments

In Figure 1, after the start 1 of the balancing out of the injection quantity, there is an initialization phase 2 in the next step, in which the adaptation data stored in an earlier regulation cycle is loaded into an engine control unit (ECU, not shown). The initialization of a new regulation cycle can be effected both after every start operation for the internal combustion engine and also after certain prescribed time or maintenance intervals.

After the end of the initialization 2, a check is carried out on the activation conditions in a passive regulation step 3. This involves waiting until the preferred operating conditions are reached for the adaptation of certain injection parameter values. These conditions include for example the load, the rotational speed, or the coolant water temperature. For this purpose it may be necessary to modify the engine control unit so that, during the subsequent adaptation, the dynamics of the time changes of the operating point, chosen for the purpose of carrying out the adaptation cycle, are limited.

As soon as the activation conditions are increased (*sic*), the actual active regulation cycle 4 is started. Using the injection parameters 5 associated with the engine operation state, regulation 6 of the duration of actuation and the duration of the recharging time is carried out. As the result of this, the injection quantities for the individual injectors in the internal combustion engine are equalized with each other at a certain operating point, and the actuation signals for the various injectors are issued at the same point in time. Full details of this will be found below in the description of

Figure 2. An additional analysis possibility which is also available at this point in the process is to infer from a torque model, for the selected operating point with the given injection parameter values, the injection quantity which must apply according to the achieved torque.

After this, in step 7 (adaptation of the actuation parameters), further injection parameters or injection parameter sets i are loaded, as applicable, and the regulation 6 is carried out for each of these, with a determination of the injection quantity differences which exist at the set value of the selected injection parameter, or with balancing out by an appropriate correction factor for an actuation parameter, as applicable. For this adaptation, a suitable actuation parameter is selected, such as for example the duration of the actuation applied to the actuator and the duration of the recharging time. The resulting adaptation values are assigned to the injection parameter set, that is primarily the injection parameters such as for example the injection pressure and the duration of the injection, whose effect on the injection quantity differences is to be defined, and are stored away so that they can be called up later during driving operation for the purpose of directly balancing up the injection quantities without a regulation cycle. When the adaptation has been carried out for a sufficient number of checkpoints (typically 5 to 10), that is for example for all the i=1 to i=K set injection parameter values for the pressure, the end 8 of the adaptation or the ongoing regulation cycle, as applicable, is reached and the stored adaptation values can be used for equalizing the injection quantities in driving operation.

Figure 2 shows the modifications to the actuator signals carried out in step 6 by changing the duration of actuation and duration of the recharging time. The upper parts of Figures 2A to C show two actuation signals for two injectors. To make it easier to show them, the actuation signals are plotted one above the other. In the lower part of the figures are plotted the valve lifts for the corresponding injectors.

In Figure 2A, the injectors are actuated by identical actuation signals. The first injector receives the actuation signal 10, the second injector the actuation signal 11. Each actuation signal is made up of a (triangular-shaped) upward-pointing recharging signal 10′ or 11′ respectively, and a downward-pointing (triangular-shaped) discharging signal 10′′ or 11′′ respectively, which starts at t_1 and ends at t_2. As can be seen, the recharging durations 10′ and 11′ and the discharge durations 10′′ and 11′′ are identical. The time interval between the end of recharging and the start of discharging (the interval from t_2 to t_3) is unchanged in all the Figures 2A to 2C. As a result of manufacturing tolerances, the same actuation signals 10 and 11 produce different valve lifts for the injectors, as can be seen from signals 13 and 14. Here, valve lift 13 corresponds to the first injector and valve lift 14 to the second injector. When the maximum needle excursion is reached (needle stop for the jet needle), the actuator for the first injector generates an actuator signal S1, at a time point of approximately 1.3 time units. The actuator for the second injector generates an actuator signal S2 at approximately 1.4 time units. As can be seen, the valve on the second injector is

raised by less than that on the first injector, in spite of the actuation signals being the same. In addition, the valve on the second injector is not raised until the point in time t_2, while this has occurred much earlier (t'_1) for the first injector. This delay is caused by the larger idle stroke of the second injector.

In Figure 2B, the actuation signal for the second injector 11 is now somewhat altered, in that the recharging time is lengthened and the duration of the actuation time. This is achieved with the end of the recharging time remaining unchanged at t_2. The duration of the actuation time is made up of the charging times (durations of the recharging and discharging times) and the time interval between the two signals. The early start of the recharging operation leads to the idle stroke being completed sooner, and hence to a faster actuation of the valve. In addition, the longer charging operation has the effect of increasing the maximum valve lift (from 16 to 16'), i.e. from 40 μm to over 50 μm, as shown in Figures 2A and 2B. Also because of the alteration to the actuation signal for the second injector, the actuator signal S2 is displaced to an earlier point in time, so that the actuator signals S1 and S2 are then closer to each other than in Figure 2A.

The sole difference from Figure 2B to Figure 2C is that the charging signal 11'''' has again been lengthened (start now at t_0), without altering the end (t_2) of this charging signal. This of course lengthens the duration of the actuation. As a result of this particular charging signal 11'''', the valve

lift for the second injector takes place simultaneously with the valve lift of the first injector, so that the lifts in the lower part of Figure 2C can no longer be separated. By modifying the durations of actuations and the durations of the recharging times, the valve lifts of the individual actuators can be adjusted so that the actuation signals S1 and S2 occur simultaneously. This simultaneity is to be understood as meaning that the actuation signal for the first injector occurs at a certain crankshaft angle for the piston, relative to top-dead-center for the piston, and correspondingly the actuation signal for the second injector occurs at the same crankshaft angle relative to top-dead-center for the piston.

During each regulation cycle 6, the last stored adaptation values or correction factors, as applicable, are overwritten by the newly determined ones, by which means account will be taken in particular of the aging symptoms which have occurred in the meantime for the injection device, which may lead to changes in the variations in respect of the injection quantities in the various combustion chambers.

Optionally it is possible, for the set operating state and from a knowledge of the engine operating state (temperature of the coolant water, active consumers), to read out from the torque model the absolute value of the injection quantity, and to use the injection quantities, say, for exact calibration of the characteristic data.